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STUDENT WORKBOOK

THREE-PHASE CIRCUITS

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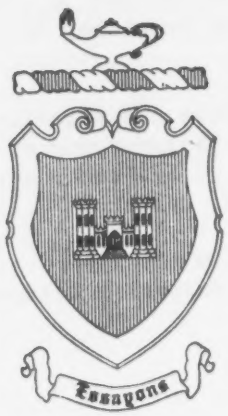

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US ARMY ENGINEER SCHOOL - FORT BELVOIR, VIRGINIA

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Three-Phase Circuits

INTRODUCTION

Most electrical equipment used today is designed to operate on alternating current. To supply power for the many types of electrical equipment AC generating systems are designed to operate at various voltages, frequencies, and number of phases.

The normal frequency of commercial power in the United States is 60 cycles per second; however special equipment may require such frequencies as 25, 50, 400, or 800 cycles. To supply power for various frequencies, special generator sets or rotary frequency converters are required.

To provide various voltages and either single or three phase power, special equipment is not required. Many voltages and either single-phase or three-phase power can be supplied by the normal generator sets used by the U. S. Army. How can this be done?

After completing this lesson you will be able to explain phase voltages and three-phase generator connections.

1. PHASE VOLTAGES

The alternating voltage used to power most electrical loads is either single-phase or three-phase. A single-phase voltage is a sine wave voltage applied to the electrical load by a two wire connection (although the distribution system may be more than two wires). A three-phase voltage is three single-phase voltages 120 electrical degrees out of phase with each other. A three-phase distribution system may be either three or four wires.

a. Single-Phase. The alternating voltage used to power lighting circuits, small motors, and other common electric loads is single-phase. A single-phase AC generator has a stator made up of a number of windings that form a single circuit in which an output voltage is generated. The AC generator may be a single voltage type (Figure 1) or a multiple voltage type.

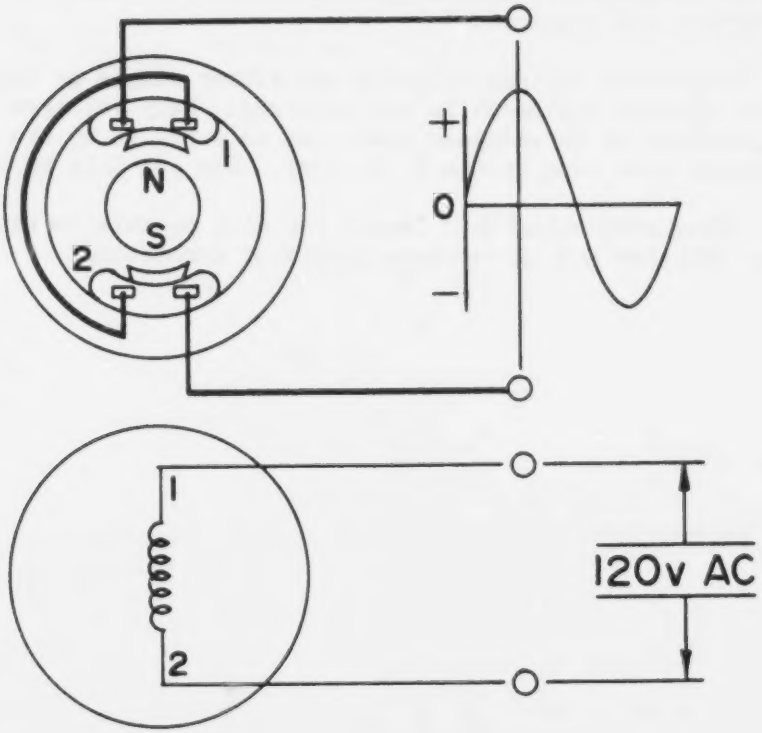

FIGURE 1 - SINGLE-PHASE AC GENERATOR

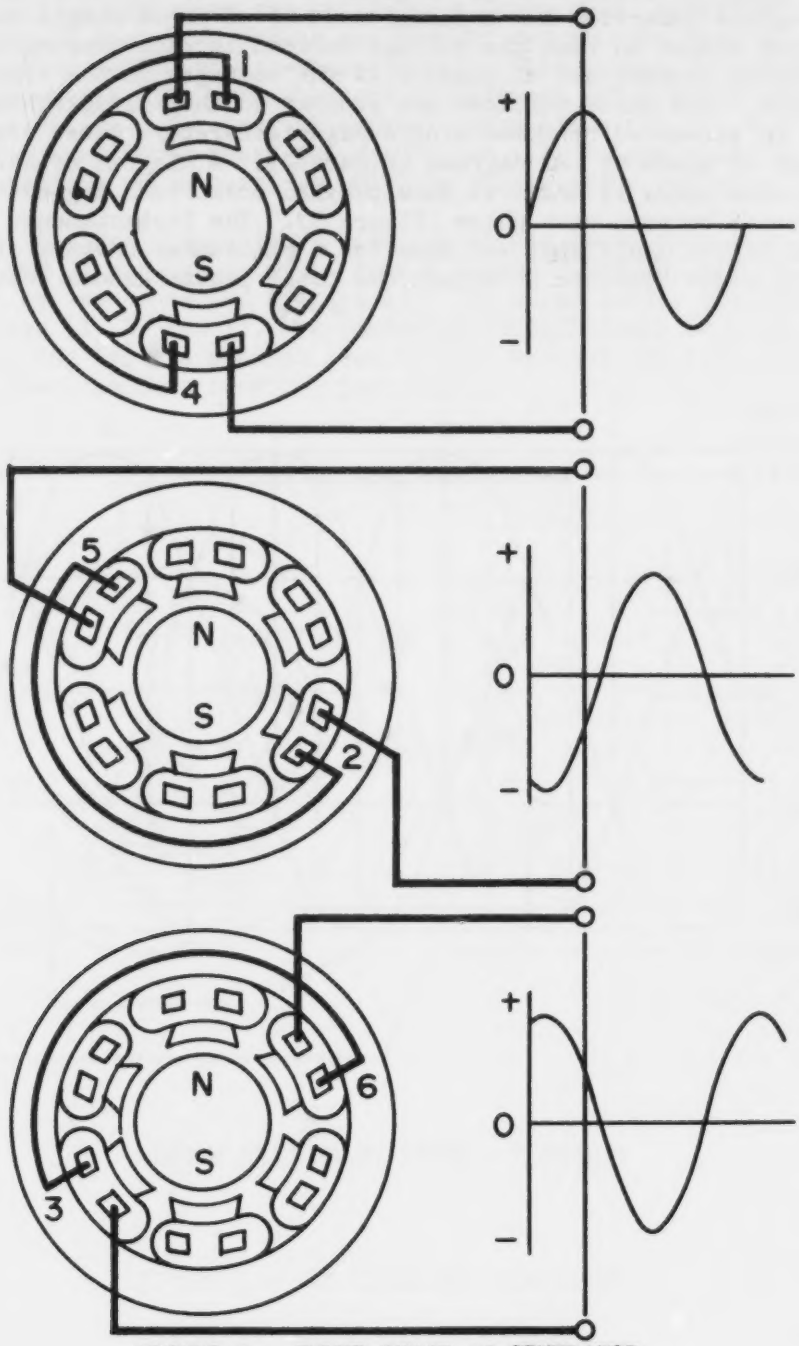

FIGURE 2 - THREE-PHASE AC GENERATOR

b. Three-Phase. The alternating voltage used to power large electric loads such as large motors is three-phase. A three-phase generator has a stator made up of three single-phase windings spaced so that the voltage induced in each winding is 120 electrical degrees out of phase with the voltages in the other two windings. The three voltages are similar to the voltages that would be generated by three single-phase generators whose voltages are out of phase by 120 degrees (Figure 2). A diagram of three-phase sine waves is drawn to show the 120 electrical degrees difference between each phase (Figure 3). The instantaneous values of the individual voltages for a particular instant of time must be added together to obtain the total instantaneous voltage.

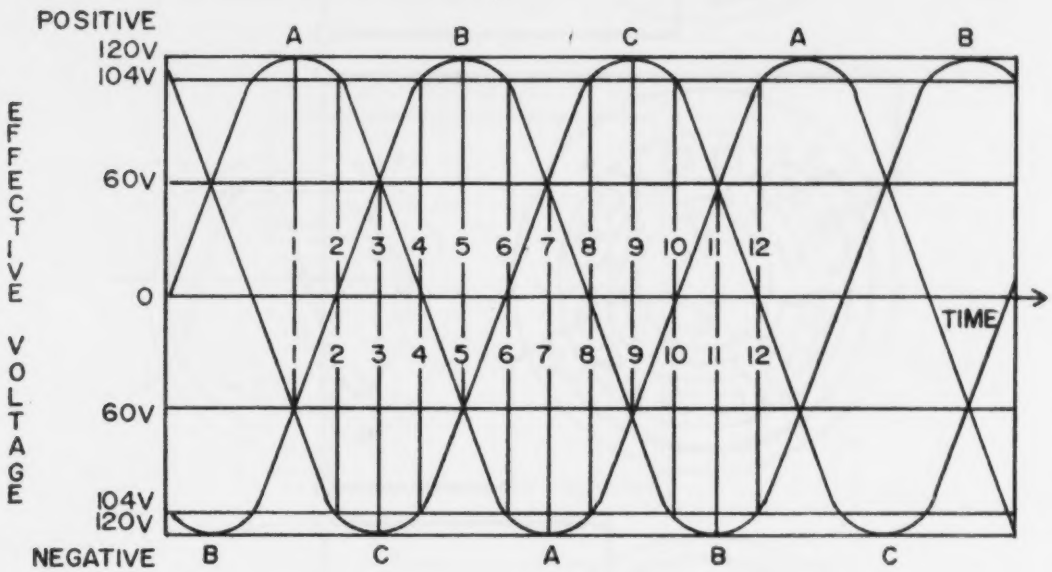

FIGURE 3 - THREE-PHASE SINE WAVES

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2. THREE-PHASE GENERATOR CONNECTIONS

In a generator set utilizing a three-phase generator, the six wires (2 from each phase) are brought out to some type of reconnection switch or tap-change board. This allows the generator to be connected into more than one arrangement and provide multiple output voltages. The two three-phase connections are the DELTA and the WYE. Some three-phase generators can also be connected in a ZIGZAG connection which provides multiple single-phase voltages.

a. Wye Connection. When one of the leads from each phase (4, 5, and 6) are connected to form a common junction, the stator is said to be wye connected (Figure 4). The other leads, one from each phase (1, 2, and 3), are connected to individual terminal posts (L_1, L_2, and L_3). A neutral lead is also brought out from the common junction to a terminal post (L_0).

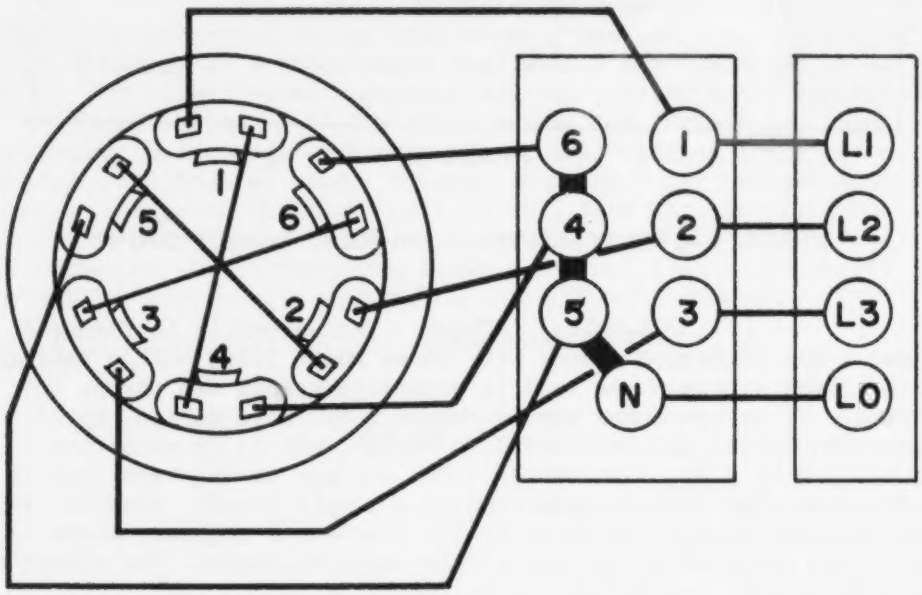


FIGURE 4 - WYE CONNECTED GENERATOR

(1) 120-Volts, 1-Phase. The simplified schematic in figure 5 shows a wye connected stator with three phase leads and a neutral lead. Each single-phase load is connected across only one phase. Thus, R_1 is connected across phase A, R_2 is connected across phase B, and R_3 is connected across phase C. The effective voltage applied to each load is the voltage of a single phase, 120 volts.

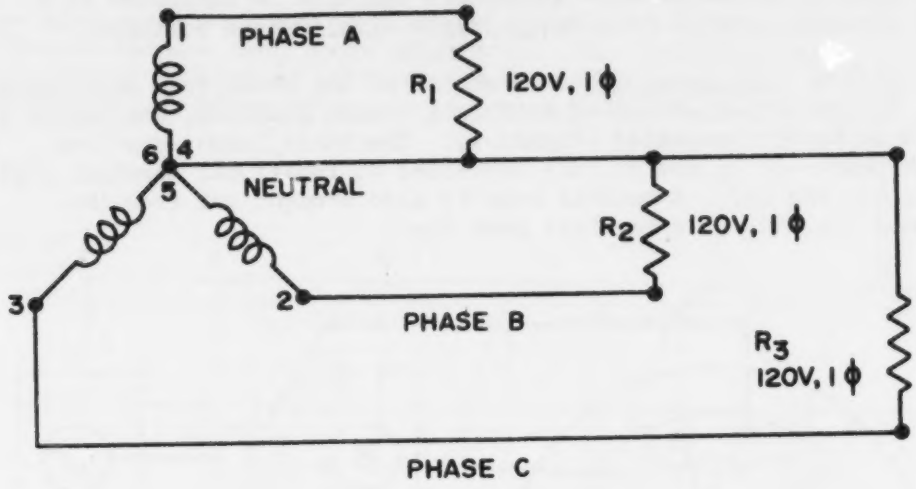


FIGURE 5 - WYE CONNECTION, 120-VOLT, 1-PHASE OUTPUT

(2) 208-Volts, 1-Phase. The schematic in figure 6 shows a wye connected stator with three phase leads but no neutral lead. Each single-phase load is connected across two phases in series. R_1 is connected across phases A and B in series, R_2 is connected across phases B and C in series, and R_3 is connected across phases A and C in series. The voltage across each load is higher than the voltage generated in a single phase. However, since the voltages are out of phase by 120 electrical degrees, there is not total addition of the two single phase voltages. The effective voltage between any two phases is 208 volts.

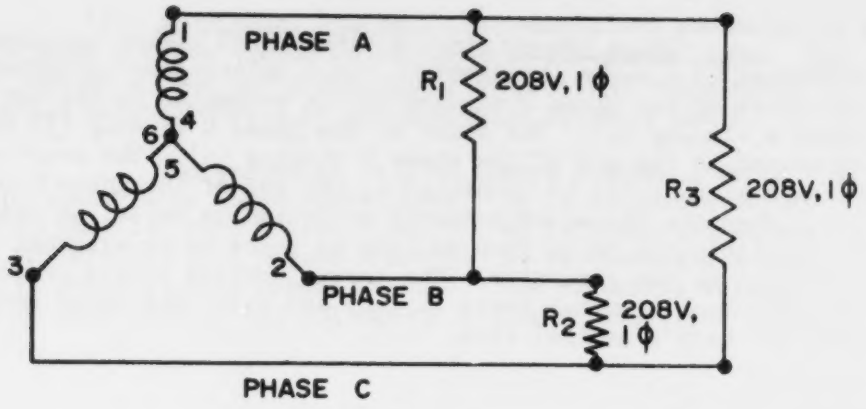


FIGURE 6 - WYE CONNECTION, 208-VOLT, 1-PHASE OUTPUT

(3) <u>208-Volts, 3-Phase</u>. The schematic in figure 7 shows a wye connected stator with three phase leads but <u>no</u> neutral lead. The load is a three-phase load with a leg connected to each phase. The effective voltage does not increase with the addition of the third phase and is 208 volts across the three-phase load. Most three phase loads such as a motor, are balanced loads* and do not require a neutral lead. However, a neutral may be used with a balanced load even though no current will flow through it. When unbalanced three-phase loads are connected or single-phase loads are connected with three-phase loads a neutral lead is required. The neutral serves as a common lead for all three phases.

*Balanced Load - same current flows through each phase.

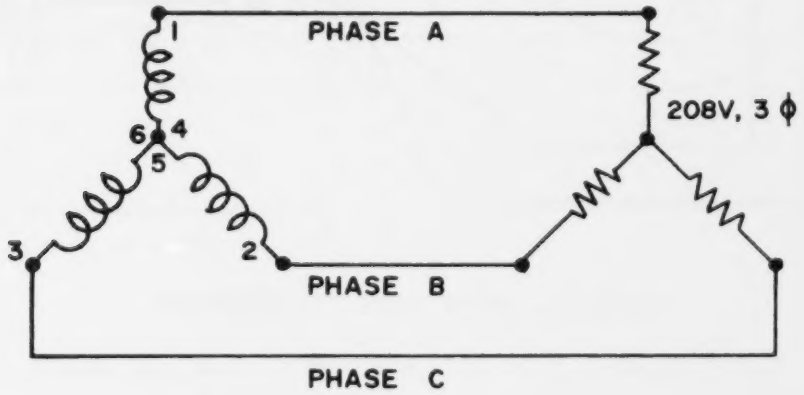


FIGURE 7 - WYE CONNECTION, 208-VOLT, 3-PHASE OUTPUT

b. Delta Connection. A three-phase stator may also be connected in a delta arrangement. In a delta-connected generator, the start of the phase B winding (2) is connected to the end of the phase A winding (4). The start of the phase C winding (3) is connected to the end of the phase B winding (5). The start of the phase A winding (1) is connected to the end of the phase C winding (6). When the phases are properly connected in delta, no current flows within the delta loop as long as there is no external load connected to the generator. The three junction points are connected to individual terminal posts (L_1, L_2 and L_3). The delta connection does not have a neutral wire.

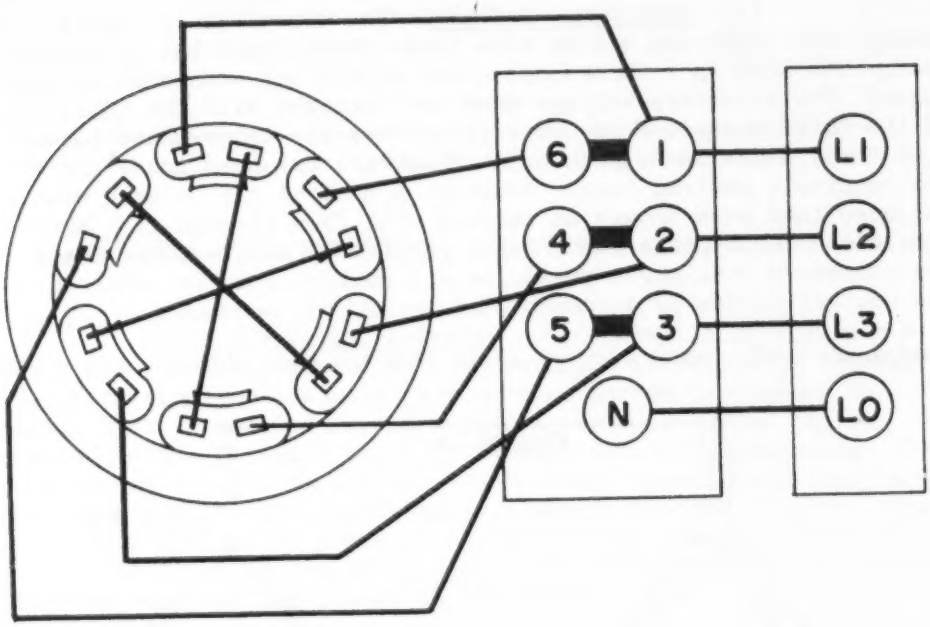


FIGURE 8 - DELTA CONNECTED GENERATOR

(1) <u>120-Volts, 1-Phase</u>. The simplified schematic in A of figure 9 shows a delta connected stator with two phase leads. The voltage applied across the single-phase load is 120 volts since it is connected across phase A in parallel with phases B and C.

The schematic in B of figure 9 shows a delta connected stator with three phase leads. R_1 is connected across phase A in parallel with phases B and C. R_2 is connected across phase B in parallel with phases A and C. R_3 is connected across phase C in parallel with phases A and B. The effective voltage applied to each load is the voltage of a single phase, 120 volts.

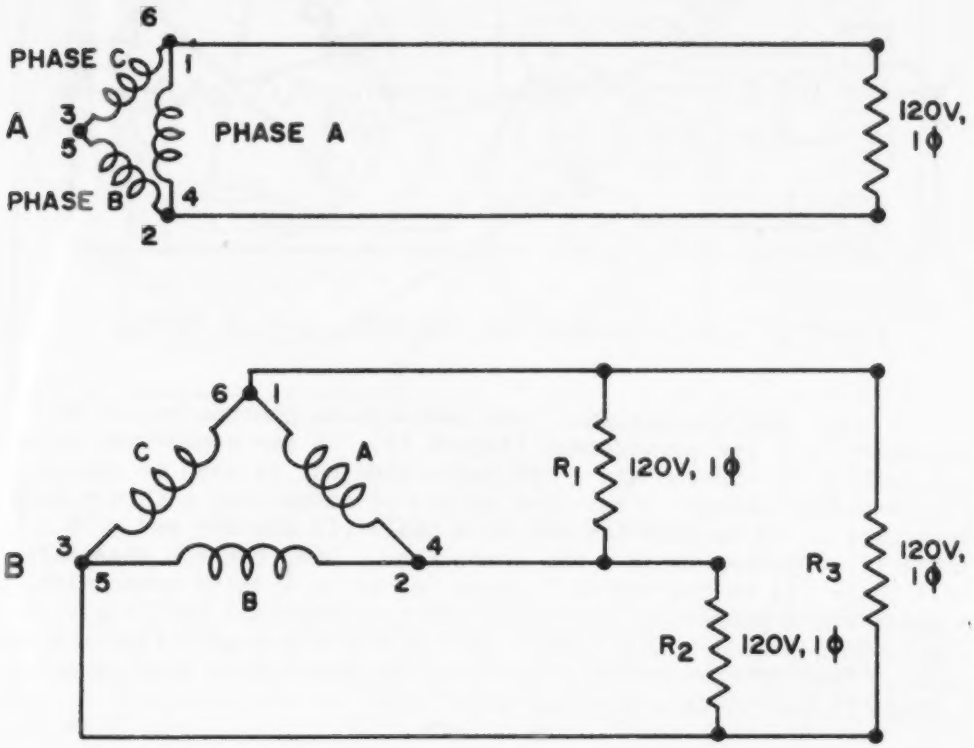


FIGURE 9 - DELTA CONNECTION, 120-VOLT, 1-PHASE OUTPUT

(2) 120-Volts, 3-Phase. The schematic in figure 10 shows a delta connected stator with three phase leads. The load is a three-phase load with a leg connected to each phase. The effective voltage applied to the three-phase load is 120 volts. A comparison of figure 10 with B of figure 9 will show that a three-phase load and a single-phase load connected across each phase are actually the same circuit. The main difference is that most three-phase loads, such as a motor, are balanced loads while single-phase loads may not be balanced.

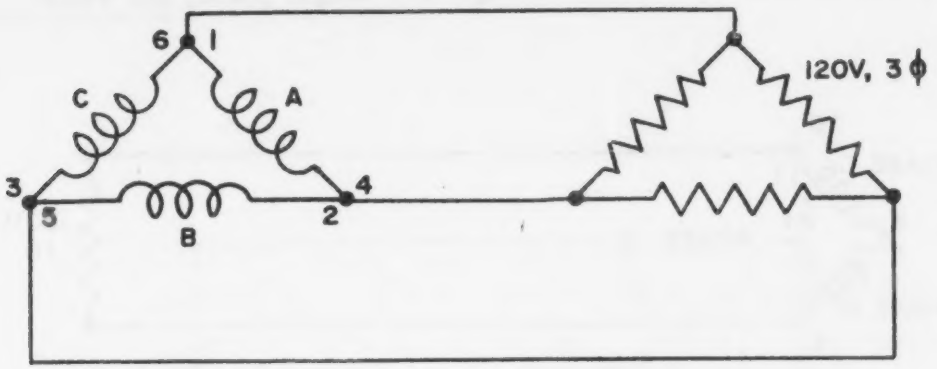


FIGURE 10 - DELTA CONNECTION, 120-VOLT, 3-PHASE OUTPUT

c. Zee Connection. Some three-phase generators can be connected in a zee arrangement (Figure 11). A zee connection is a combination of a delta and a wye connection but is used to supply single-phase voltages only. One method of connecting a three-phase generator is to connect the end of A phase (4) and the end of B phase (5) together as in a wye connection. Then connect the start of A phase (1) to the end of C phase (6) as in a delta connection. A lead from B phase (2) is brought out to a terminal post (L_2). A lead from C phase (3) is brought out to a terminal post (L_3). A neutral lead is also brought out from the junction of A phase and B phase (4 and 5) to a terminal post (L_0).

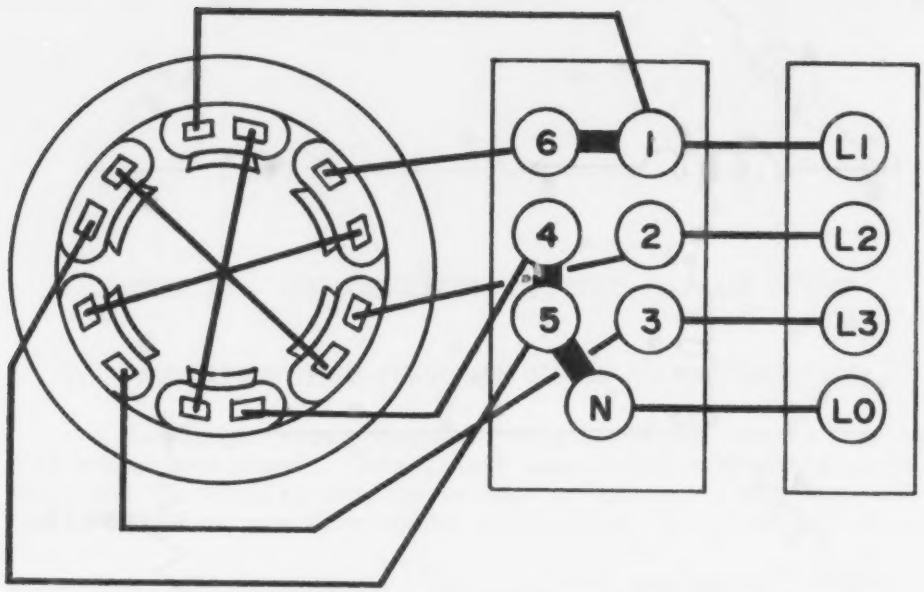


FIGURE 11 - ZEE CONNECTED GENERATOR

(1) 120 Volts, 1-Phase. The simplified schematic in A of figure 12 shows a zee connected stator with one phase lead and a neutral lead. The single-phase load is connected across only one phase of the generator so the effective voltage applied to the load is 120 volts.

The schematic in B of figure 12 also shows a zee connected stator with one phase lead and a neutral lead. The single-phase load is connected across two phases of the generator. However, since the two phases are connected the same as they are for a delta connection the effective voltage is still only 120 volts.

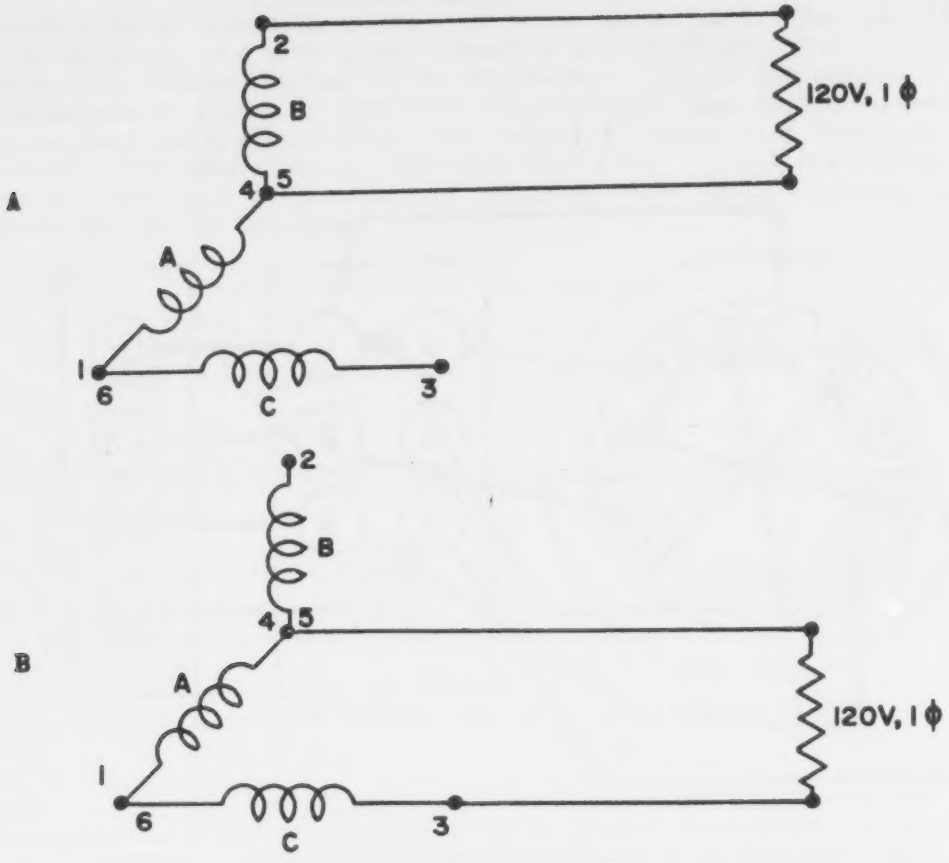


FIGURE 12 - ZEE CONNECTION, 120-VOLT, L-PHASE OUTPUT

(2) 240 Volts, 1-Phase. The schematic in figure 13 shows a zee connected stator with two phase leads. The single phase load is connected across all three phases of the generator. Since B phase provides an effective voltage of 120 volts and A and C phases combined provide an effective voltage of 120 volts, the total effective voltage applied to the load is 240 volts.

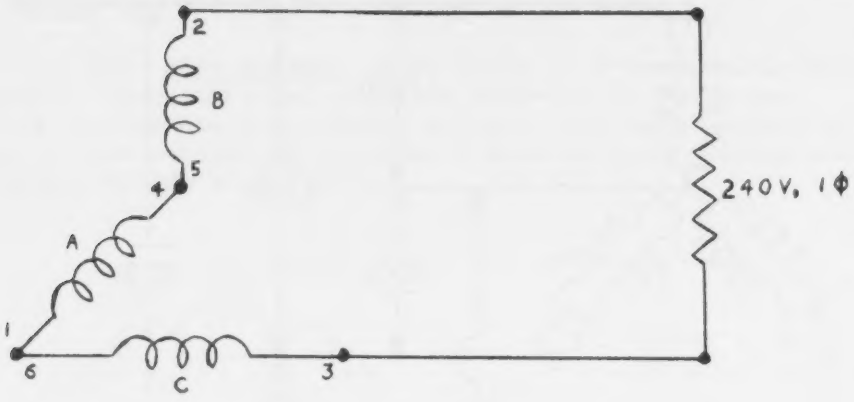


FIGURE 13 - ZEE CONNECTION, 240-VOLT, 1-PHASE OUTPUT

3. COMBINATION THREE-PHASE AND SINGLE-PHASE CONNECTIONS

The larger size generator sets (15-KW and above) have two coil groups per phase. This allows each individual phase to be connected in parallel for low voltage or in series for high voltage. The three phases are then connected together in wye or delta.

a. Wye Connection. The schematic in figure 14 shows low voltage and high voltage wye connections.

(1) Low voltage. A of figure 14 shows a wye-parallel connection. Each individual phase is connected in parallel and therefore does not increase the single-phase voltage. The wye connection provides a phase-to-phase voltage and a three-phase voltage of 208 volts.

(2) High voltage. B of figure 14 shows a wye-series connection. Each individual phase is connected in series and therefore doubles the single-phase voltage. The wye connection voltage is also doubled and provides a phase-to-phase voltage and a three-phase voltage of 416 volts.

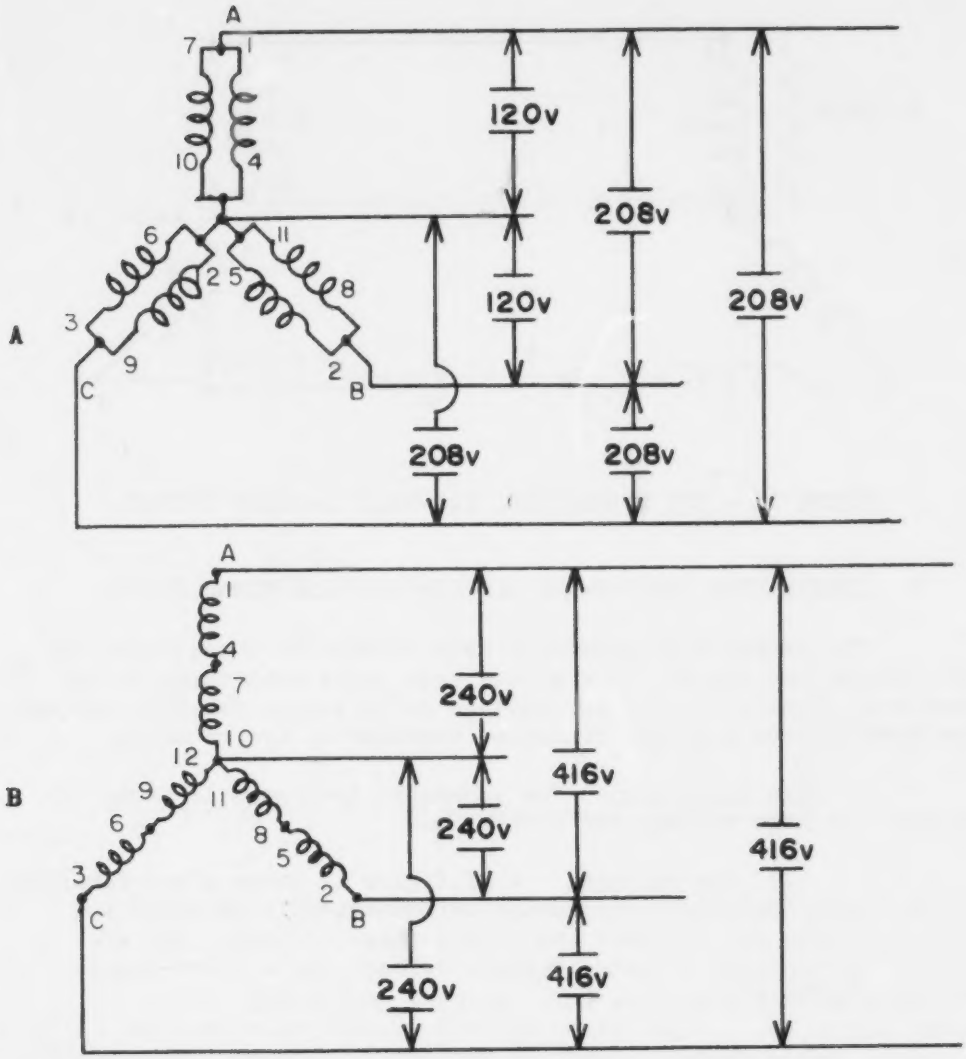


FIGURE 14 - WYE-PARALLEL AND WYE SERIES CONNECTIONS

b. Delta Connection. The schematic in figure 15 shows low voltage and high voltage delta connections.

(1) Low voltage. A of figure 15 shows a delta-parallel connection. Each individual phase is connected in parallel and

therefore does not increase the single-phase voltage. The delta connection also does not increase voltage and provides a phase-to-phase voltage and a three-phase voltage of 120 volts.

(2) <u>High voltage</u>. B of figure 15 shows a delta-series connection. Each individual phase is connected in series and therefore doubles the single-phase voltage. The delta connection voltage is also doubled and provides a phase-to-phase voltage and a three-phase voltage of 240 volts.

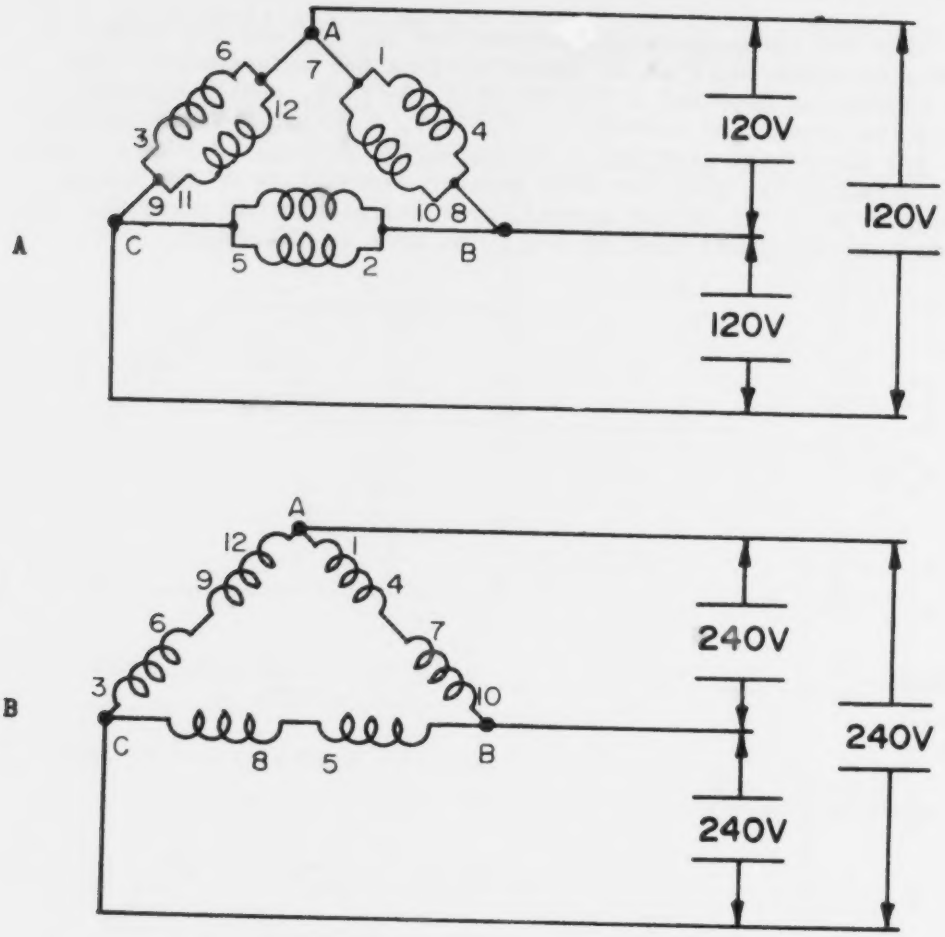


FIGURE 15 - DELTA-PARALLEL AND DELTA-SERIES CONNECTIONS

SUMMARY

The alternating voltage used to power most electrical loads is either single-phase or three-phase. Most AC generator sets have the capability of providing power for either type of load. The smaller generator sets (3, 5, and 10 KW) used by the U. S. Army are capable of supplying 120, 208, or 240 volts, single-phase and 120 or 208 volts, three-phase. This capability is provided by the use of reconnection switches or a tap-change board which allows the generator stator to be connected in more than one arrangement.

The two three-phase connections are the wye and the delta. Some generators can also be connected in a zee arrangement. The wye connection provides a 120/208-VOLT, 3-PHASE, 4-WIRE circuit. The delta connection provides a 120-VOLT, 3-PHASE, 3-WIRE circuit. The zee connection provides a 120/240-VOLT, 1-PHASE, 3-WIRE circuit. This versatility, plus the even greater versatility of the larger generator sets (15 KW and above), provides electrical power for the electrical equipment used by the U. S. Army in the field.

STUDY QUESTIONS

1. The alternating voltage used to power most electrical load is either single-phase or _____phase.

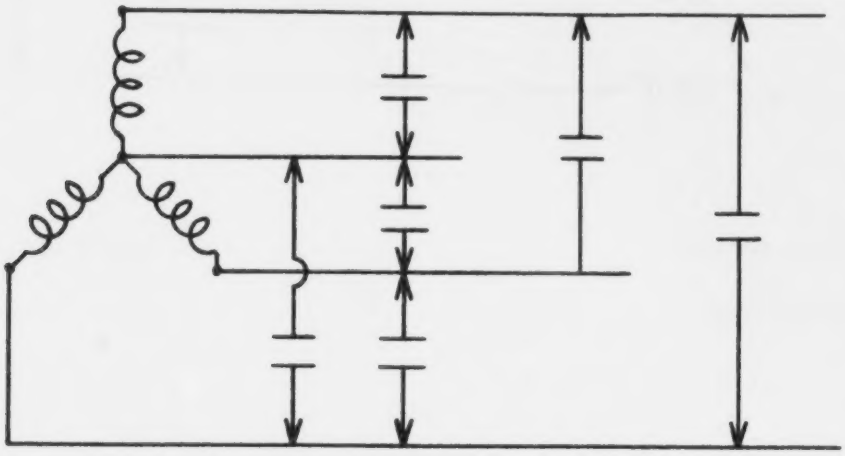
2. Three-phase voltage are the same as three single-phase voltages _____ degrees out of phase.

3. The two three-phase connections are _____ and _____.

4. A wye connection provides a _____ /_____ -VOLT, and _____-PHASE, _____-WIRE circuit.

5. Fill in the effective voltages.

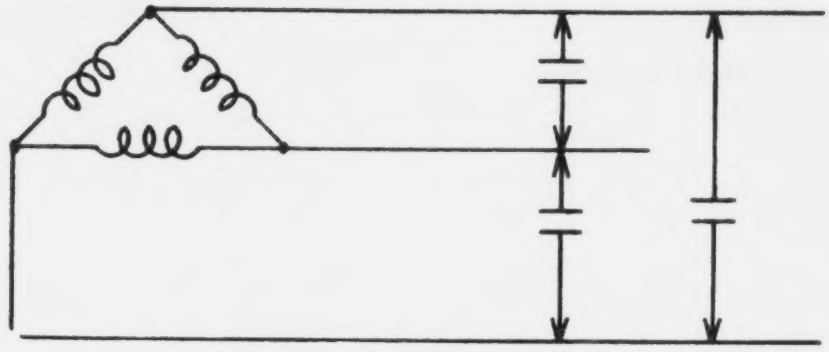
A



6. A delta connection provides a _____-VOLT, _____-PHASE, _____-WIRE circuit.

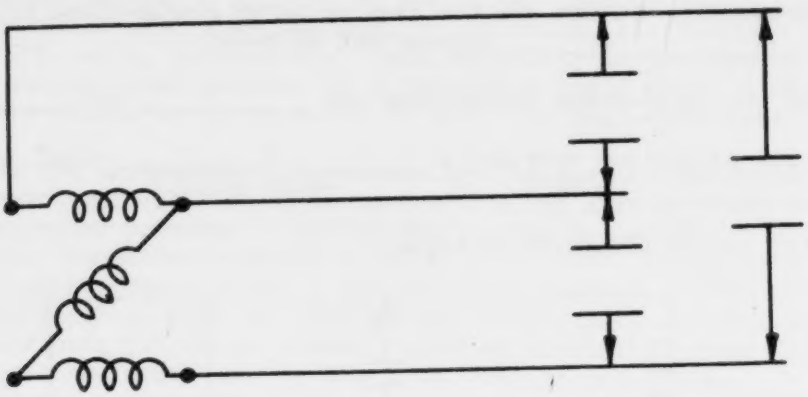
7. Fill in the effective voltages.

B



8. A zee connection provides a _____-VOLT, _____-PHASE _____-WIRE circuit.

9. Fill in the effective voltages.



STUDENT NOTES:

INTRODUCTION

DEVELOPMENT

1. PHASE VOLTAGES

2. DELTA CONNECTION

3. WYE CONNECTION

4. ZEE CONNECTION

5. METHODS OF MAKING CONNECTIONS

6. TYPICAL CHANGE BOARD

SUMMARY

☆U.S. Government Printing Office: 1986—491-036/52443